Georgia Department of Transportation's Progress in Open-Graded Friction Course Development

(Note: The text of this paper is an edited version of the paper bearing the same title in *Transportation Research Record 1616*).

Abstract

In order to improve the safety of motorists on Georgia highways, the Georgia Department of Transportation (GDOT) has continued to use the most advanced and effective pavements available, including the open-graded friction course (OGFC). Since OGFC was conceived in the 1950's and 1960's, GDOT has used this mix as a thin porous wearing layer, primarily on interstate highways.

In the past, GDOT encountered problems with OGFC use, including asphalt cement (AC) draindown, rapid oxidation, raveling, and stripping of underlying layers. Consequently, GDOT placed a moratorium on OGFC use in 1982. Since that time, however, several modifications have been made to improve the performance of OGFC mixes. Hydrated lime is added as an antistripping agent to OGFC and to all other mixes used on the Georgia state route system, including dense-graded mixes which underlie OGFC. Fibers are added to eliminate AC draindown. Polymer-modified AC is added to improve the durability of the pavement by reducing problems associated with premature oxidation and raveling. Production temperatures are increased to more thoroughly dry aggregate components and thus improve AC adhesion. Finally, coarser gradations and thicker layers are used to improve permeability.

With the modifications made to OGFC in recent years, significant improvements in mix performance have already been noted. Agencies which have used this mix in the past and experienced problems similar to those experienced by GDOT should consider the possibility of using modified OGFC on high-volume traffic facilities.

I. Introduction

As traffic levels on Georgia highways continue to increase, GDOT has sought to improve safety for motorists by utilizing the most advanced and effective pavements available. Open-graded friction course (OGFC) is one type of pavement that has been developed and improved in recent years which can improve motorist safety.

The primary benefit of using OGFC is the rapid removal of surface water from roadways during light to moderate rainstorms, reducing hydroplaning and increasing driver safety. By draining water through the pores of the mix instead of across the mix surface, the coefficient of friction between vehicle tires and the driving surface is improved. Additionally, OGFC reduces splash and spray, improves nighttime visibility, and improves the visibility of traffic striping.

Since the earliest conception of OGFC, GDOT has attempted to modify this mix in order to achieve the highest level of performance possible. Due to the success experienced after these modifications were made, GDOT has implemented a policy of using OGFC as the final ride surface on all interstate projects and state routes which have daily traffic volumes exceeding 25,000 and are not in reduced speed zone areas. Approximately 850,000 tons of OGFC have been placed on Georgia highways since 1993.

II. Material Composition of OGFC

Since OGFC was conceived in the 1950's and 1960's, GDOT has used this mix as thin porous wearing layers primarily on interstate highways. The early mix used was very susceptible to premature failure due to weathering. In the early 1990's however, GDOT developed the 12.5 mm OGFC, which is now the standard GDOT mix. This mix, which has been used extensively statewide since 1993, is composed of aggregate, polymer-modified asphalt cement (PMAC), stabilizing fibers, and hydrated lime. It has been typically applied at a spread rate of 75 lb./yd.^{2}, which is equivalent to a lift thickness of 5/8 inch. More recently, however, the spread rate has been increased to 90 lb./yd.^{2}.

OGFC is typically gap-graded and thus contains high percentages of single-size coarse aggregate. OGFC typically has a high asphalt cement (AC) content, a thick AC film, a low percentage of material passing the 0.075 mm (#200) sieve, high volumes of in-place air voids (10-20%), and an in-place thickness less than one inch. The inclusion of PMAC gave the mix greater film thickness, which safeguards against the weathering problems experienced by cements in earlier mixes. Mineral fiber has also been added to the 12.5 mm OGFC, typically 0.4% of the total mix. This ingredient stabilizes the binder during mixing and placement to protect against draindown, and it also enhances the material strength through the interlocking of fibers in the thick AC coating. Hydrated lime is added as an antistripping agent to OGFC and to all other mixes used on the Georgia state route system, including dense-graded mixes which underlie OGFC.

GDOT began evaluating porous European mix (PEM), a form of OGFC, in 1992. PEM has proven to be more permeable than conventional OGFC. This improved drainage is attributable to the coarser gradation and increased lift thickness of PEM (1.25 in.). PEM is typically applied at a spread rate of 135 lb./yd.^{2}. As of September 2001, GDOT specifications require the use of PEM on all interstate paving projects where stone matrix asphalt (SMA) is required. SMA is generally specified where average daily traffic (ADT) exceeds 50,000.

As materials specifications for OGFC developed, GDOT sought to continually improve the characteristics of the mix materials. The specifications for basic aggregate properties, including soundness and abrasion, were not altered during the development of this mix; however, the aggregate gradations and the binder specification test procedures have been modified to enhance the permeability and durability of OGFC.

A. Gradation

Encouraged by results with the porous European mix, GDOT began experimenting with a hybrid OGFC design. In the summer of 1992, OGFC specifications were changed to require a coarser gradation, a polymer modifier, and mineral fibers in addition to the previously specified hydrated lime anti-strip additive. A research project (GDOT RP 9110) was developed to evaluate the effectiveness of these changes and to determine whether more improvements were necessary. The project verified the efficacy of coarsening the mix gradation. The coarser gradation enhanced permeability and resistance to rutting.

The job mix formulas and design limits for OGFC and PEM are shown in Table 1, and the basic properties of aggregates used in OGFC and PEM are shown in Table 2. The 12.5 mm OGFC mix drains 2 to 3 times more water than the older conventional OGFC ("D" mix). The 12.5 mm OGFC is approximately 15% coarser than the "D" mix, in order to provide a more positive drainage network. Likewise, the PEM is approximately 10% coarser than the 12.5 mm OGFC.

TABLE 1. Job Mix Formulas and Design Limits for Open-Graded Friction Course and Porous European Mix

Mix Control Tolerance	Asphaltic Concrete	9.5 mm OGFC	12.5 mm OGFC	12.5 mm PEM
	Gradation Requirements		***% Passing***	
±0.0	% Passing 19 mm Sieve	-	100	100
±6.1	% Passing 12.5 mm Sieve	100*	85-100	90-100
±5.6	% Passing 9.5 mm Sieve	85-100	55-75	35-60
±5.7	% Passing 4.75 mm Sieve	20-40	15-25	10-25
±4.6	% Passing 2.36 mm Sieve	5-10	5-10	5-10
±2.0	% Passing 75 μm Sieve	2-4	2-4	1-4
	Design Requirements			
±0.4	Range for % AC	6.0-7.25	-	5.5-7.0

*Mix Control Tolerance not applicable to this sieve for this mix.

TABLE 2. Basic Properties of Aggregates Used in Modified Open-Graded Friction Course and Porous European Mix[a]

Parameter	Requirement
Los Angeles abrasion (loss)	< 50%
Soundness (loss)[b]	< 15%
Flat and elongated particles allowed (5:1 ratio)	< 10%
Mica schist allowed	< 10%

[a]Silica-rich aggregates only shall be used (e.g. granites). Carbonate-rich aggregates (e.g. limestones) are excluded.
[b]Soundness loss is measured using magnesium sulfate ($MgSO_4$). Typical loss is less than 2%.

B. Polymer-Modified Asphalt Cement

GDOT has primarily used two polymers, styrene butadiene (SB) and styrene butadiene styrene (SBS), to modify cements used in OGFC. GDOT determined that the inclusion of these polymers resulted in three main improvements to the mix: (1) the binder stiffness increased to 8-10 times that of neat AC; (2) the softening point of the AC was increased approximately 40°F, and (3) the AC film was more ductile and flexible than that of unmodified AC. In addition to providing greater stiffness at higher temperatures, polymer-modified asphalt cement (PMAC) has proven to be more ductile at cold temperatures than neat asphalt. This should provide more resistance to low temperature cracking.

A comparison of the properties of AC modified with polymer and neat AC was made, and test results indicated that the polymer blend was much more viscous than the base AC (AC-20) and that it was much more elastic. The AC-20 modified with polymer could recover from elongation almost four times better than the base AC, as shown in the elastic recovery test. Thin-film aging had very similar effects on both the polymer blend and the neat AC, but the polymer blend remained almost three times more ductile at 39°F. Due to the greater viscosity of the polymer blend, temperature requirements in the design procedure were increased to 300°F.

Since the development and implementation of Superpave binder grading, empirical tests have been dropped, and Superpave PG76-22 binder is now used. A phase angle requirement of less than 75° has been added to help ensure that polymer modification is used to meet the binder grade requirements. This value was obtained through Superpave binder tests on generic PMACs previously used by GDOT. On many of the first GDOT projects, PMAC was modified at the plant site. Since the demand for PMAC has increased since 1993, terminal blending is becoming the standard practice. Polymer modification of asphalt cement is typically accomplished with special blending equipment capable of imparting high shear into the blend. The base asphalt cement has typically been modified with about 4.0-4.5% polymer by weight of AC.

C. Mineral Fibers

The inclusion of mineral fiber resulted in several additional improvements to the mix. Fibers are generally used in OGFC to stabilize the AC film surrounding aggregate particles in order to reduce AC draindown during production and placement. Film thickness was increased through the addition of fibers by nearly 400% over conventional dense-graded mixes, and it was 30-40% thicker than for standard OGFC. This film thickness is based on gradation and calculated surface area. Test results also indicate that the addition of fiber permitted greater AC contents.

GDOT normally uses mineral fibers in OGFC at a dosage rate of 0.4% by weight of the total mix. GDOT discovered that a certain interlocking occurred among the fibers and between the coated aggregate particles. This phenomenon not only vastly improves bonding, but it significantly strengthens the mix and virtually eliminates AC draindown.

GDOT specifications now allow the inclusion of cellulose fibers as well as mineral fibers. GDOT normally uses cellulose fibers in OGFC at a dosage rate of 0.3% by weight of the total mix. The benefits of mineral fiber addition are also true of cellulose fiber addition, but GDOT has achieved even greater control of fiber addition with the cellulose fibers, which are pelletized and more easily metered than blown mineral fibers.

III. Film Coating and Draindown Characteristics of OGFC

The modified OGFC mix has a 30-40% thicker film coating than the conventional OGFC mix. This thicker film is primarily the result of coarsening the gradation, which reduces the aggregate surface area to be coated. The use of PMAC and mineral fibers in the modified OGFC also contributes to the thicker film. The thicker film has proven to reduce the aging and raveling problems encountered in the past.

The conventional OGFC was placed at very low temperatures (230-250°F) because of excessive AC draindown during production and hauling. The modified OGFC can now be produced at much higher temperatures than conventional OGFC without draindown problems because of the addition of polymers and fibers. Typical mix temperatures now range from 320-338°F.

The draindown susceptibility of GDOT modified OGFC can be determined using a test developed by the National Center for Asphalt Technology (NCAT). A mix with an optimum AC content is placed in a small wire basket having ¼-in. mesh openings, and heated 25°F above normal production temperature (typically 350°F) for one hour. The amount of cement which drains from the mix is measured.

Test results indicated that the draindown susceptibility of a mix containing neat AC had unacceptable draindown. A mix with PMAC showed less draindown, but the level was still unacceptable. Finally, with a mix containing PMAC and fibers, there was exceptionally lower draindown. The NCAT procedure specifies that 0.3% is the maximum permissible draindown, if the integrity of the mix is to be retained. Modified OGFC which contains fibers and polymers has met this requirement. Unmodified OGFC, however, has not.

IV. Plant Modifications Required for Production of OGFC Mixes

Three major modifications are typically made to the existing plants for the production of modified OGFC. These modifications have been necessary due to the additional materials required.

1. Separate fiber hopper and feeding system. Mineral fibers have been added manually at batch plants through an opening in the weigh hopper. In the first projects requiring fibers, the fiber had been packed in pre-weighed bags and manually added per batch as required. Today, fibers are introduced both in batch and drum mix plants via a separate fiber hopper and feeding system. Fibers are fluffed and blown at a specified rate into the drum at drum mix plants and into the mixing chamber at batch plants. The handling of fibers is also an area of concern. Fiber clumping can occur during mixing. GDOT has found that increasing dry and wet mixing times can correct this problem.

2. Terminal blending of asphalt cement. In the first projects requiring asphalt cement modification, AC was routed from the storage tanks into a trailer-mounted blending unit where the polymer chips were added for mixing. After mixing, the modified AC was dispersed into the aggregate during mix production. At the present time, however, polymer modification of asphalt cement occurs at the centralized AC terminal. Through terminal blending greater quality control is achieved. Terminal blending is also advantageous since it provides the capability of producing modified OGFC with certified test results available prior to use.

3. Higher asphalt cement temperature. Due to the stiffness of the PMAC and the presence of mineral fibers, the mixing temperature was increased to 325°F to provide greater workability. This higher temperature completely removes moisture in the aggregate and promotes better adhesion of the asphalt than with OGFC of the past.

Past mix was typically heated to only about 230°F, due to draindown problems at higher temperatures. The improved bond, along with the more durable polymer-modified asphalt cement, will help reduce the problems of premature oxidation and raveling that were very widespread in earlier conventional OGFC.

V. Construction of OGFC Mix

Placement of modified OGFC is more difficult than placement of either conventional dense-graded mixes or conventional OGFC. The mix is extremely stiff and tends to "set up" quickly. Maintaining a continuous operation and keeping "everything hot" is critical in producing a smooth pavement. In previous years, the modified OGFC has been typically placed at a spread rate of 75 lbs./yd.^{2}, which is equivalent to an approximately 5/8-inch thickness. Since the mat thickness is only slightly larger than the maximum aggregate size, a slight grade change can lead to pulling and streaking of the mat. For this reason the recommended spread rate has been increased to 90 lb./yd.^{2}.

The most severe problem is the formation of "cold lumps" in the mix during transport. These lumps can drag and tear under the screed, leaving severe surface blemishes and reducing the drainage effectiveness and smoothness of the mat. This problem has been typical on modified OGFC projects, especially those placed during cooler weather, even though truck beds are required to be insulated.

Surface blemishes in this mix are extremely difficult to correct. In most cases, mix is placed in the blemished areas and patted down with the backside of a shovel or raked with a garden rake. Blemishes of this nature will make it difficult to meet smoothness requirements and will decrease the drainage effectiveness in that area of the pavement.

In cases where smoothness requirements are difficult to meet, a material transfer device may be necessary to employ. In order to minimize the occurrence of "cold lumping," GDOT has placed modified OGFC at significantly higher temperatures than conventional OGFC, with close attention given to proper truck tarping and continuity of operations. A material transfer vehicle (MTV) with remixing capability helps to maintain uniform temperature, eliminates problems with cold lumps, and aids in improving pavement smoothness by facilitating a continuous operation.

Pavement smoothness, measured with a laser road profiler, showed that modified OGFC can be placed with significantly higher smoothness than dense-graded surface courses. The smoothness levels on one project, consisting of over 85 lane-miles of modified OGFC overlay, averaged only 9 in./mi. (143 mm/km). During fiscal year 1996, the average smoothness level statewide for modified OGFC was 10 in./mi. (158 mm/km), whereas dense-graded mixes averaged 25 in./mi. (397 mm/km).

VI. Permeability Characteristics of OGFC

The most important feature of OGFC is permeability, which is the measure of a material's ability to transmit fluids through a specific medium. As stated before, the primary benefit of using OGFC is the rapid removal of surface water from roadways during light to moderate rainstorms, reducing hydroplaning and increasing driver safety. By draining water through the pores of the mix instead of across the mix surface, the coefficient of friction between vehicle tires and the wet driving surface is increased.

This coefficient of friction is supplemented by the gradation of the modified OGFC, which is slightly coarser than conventional OGFC. Furthermore, splash and spray is reduced, and the visibility of traffic stripes is improved by the permeability of OGFC. The laboratory mix designs for OGFC and PEM, respectively, specify 18-20% air voids and 20-24% air voids.

GDOT performs permeability testing using the falling head permeameter. This device allows the user to determine a permeability coefficient, represented in feet (meters) per day, for the mix being tested. The apparatus consists of a circular base plate, a grease gun, and a cylindrical plastic water container. The base plate is fitted with two rubber O-rings mounted near the outer edge and placed ¾-inch apart. The base plate is placed in contact with the pavement surface, and grease is pumped between the O-rings, resulting in an impermeable seal. The plastic cylinder is then filled with water, which is allowed to flow through the base plate into the pavement below. By timing the flow of 1600 ml of water, a permeability coefficient can be calculated which is based on the known thickness of the pavement.

Testing has shown that modified OGFC typically drains 240 ft./day (73 m/day), far better than conventional OGFC (130 ft./day, 39 m/day). PEM drains approximately 340 ft./day (100 m/day). Figure 1 illustrates the comparative permeabilities of conventional OGFC, modified OGFC, and PEM. Due to the exceptional permeability of PEM, GDOT specifications now require use of PEM on all interstate paving projects where typical cross-slopes would drain water across three or more lanes in the same direction.

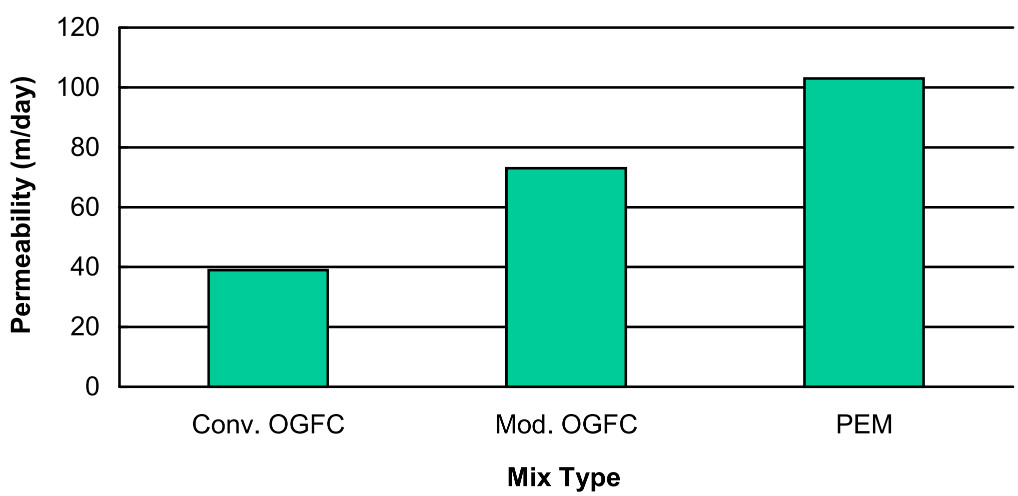

FIGURE 1. Permeability Coefficients for Open-Graded Friction Courses and Porous European Mix

VII. Cost Considerations for OGFC

The cost of modified OGFC is approximately 34% higher than that of conventional OGFC. The additional cost is incurred from the extra components in the mix, as well as the equipment needed to properly introduce these components into the mix production. Increased production temperatures and slower production rates also contribute to increased production costs.

A life-cycle cost comparison was made between standard OGFC used in the past and the modified OGFC currently used. A typical interstate roadway consisting of three 12-ft. lanes, a 10-ft. inside shoulder, and a 12-ft. outside shoulder was used for this comparison. The OGFC surface would typically overlap 12 in. onto the inside shoulder and 18 in. onto the outside shoulder.

The conventional OGFC was placed at a spread rate of 60 lb./yd.^{2}, while the modified OGFC is placed at 90 lb./yd.^{2} The additional thickness is necessary due to the coarser gradation requirements for the modified OGFC.

A typical service life of 8 years was used for the standard OGFC. The modified OGFC is expected to last 10-12 years. Based on annualized costs, the modified OGFC would become a cost-effective alternative if it lasted just 19 months longer than the conventional mix. Modified OGFC is therefore an attractive, cost-effective alternative over conventional OGFC.

VIII. Current OGFC Research

A national pooled-fund study of new-generation OGFC is underway, under the direction of NCAT. The objective of this study is to refine and field validate the new-generation OFGC mix design procedure developed by NCAT in 1999. This procedure was developed via the result of a lab study which evaluated factors that had led to poor OGFC performance reported around the United States. The proposed mix design method addresses the shortcomings in previous OGFC mix design procedures but, as above, needs refining and field verification. Additionally guidelines for the production and construction for the new-generation OGFC are to be developed. Several states have volunteered construction projects as test sites for the study.

IX. Conclusions

GDOT, along with other state transportation agencies, has experienced problems with OGFC in the past. The problems of asphalt cement draindown, rapid oxidation, raveling, and stripping of underlying layers were severe enough that GDOT placed a moratorium was placed on the use of the mix in 1982. Since that time, however, several modifications have been made to improve the performance of OGFC. Hydrated lime is added as an antistripping agent to OGFC and to all other mixes used on the Georgia state route system, including dense-graded mixes which underlie OGFC. Fibers are added to eliminate draindown of asphalt cement. PMAC is added to improve the durability of the cement by reducing problems associated with premature oxidation and raveling. Production temperatures are increased to more thoroughly dry aggregate components and thus improve AC adhesion. Finally, coarser gradations and thicker layers are used to improve permeability.

The benefits of using modified OGFC and PEM far outweigh the difficulties that may be encountered during production and placement. The improved permeability of these mixes results in reduced potential for hydroplaning, reduction of splash and spray, improved friction, better nighttime visibility, and better visibility of traffic striping. With the modifications made to OGFC in the last few years, significant improvements in mix performance have already been noted. Agencies which have used OGFC in the past and experienced problems similar to those experienced by GDOT should reconsider the possibility of using modified OGFC or PEM on high-volume traffic facilities. It is now GDOT policy to use modified OGFC as the final ride surface on all interstates and on state routes which have daily traffic volumes exceeding 25,000 and are not in reduced speed zone areas.